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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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**Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation**

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Magnetic resonance imaging apparatus

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(44)

The present invention relates to a magnetic resonance imaging (MRI) apparatus and to a magnetic resonance imaging method. Such an MRI apparatus and MRI method are generally known and widely used. Therein a magnet is used for generating a temporarily constant, uniform magnetic field through an examination region, and a radio frequency (RF) unit comprising an RF coil system is used for transmitting radio frequency signals into the examination region to induce and manipulate magnetic resonance of dipoles disposed in the examination region and/or for receiving RF signals from the dipoles disposed in the examination region.

10 The article "SENSE: Sensitivity Encoding for Fast MRI", Klaas P. Pruessmann et al., Magnetic Resonance in Medicine 42:952-962 (1999) describes a concept for considerably enhancing the performance of magnetic resonance imaging by means of arrays of multiple receiver coils. Therein sensitivity encoding (SENSE) is described which is based on the fact that receiver sensitivity generally has an encoding effect complementary to

15 Fourier preparation by linear field gradients. By making use of an array of simultaneously receiver coils scan time can be reduced and resolution can be increased. The described method takes advantage of undersampling or reduction of k-space samples and known individual coil sensitivity profiles. Since sampling is performed with a step size larger than prescribed by the Nyquist theorem the so-called foldover occurs during the (always

20 necessary) Fourier transformation, so that in principle two different points from the physical image space cannot be distinguished from one another.

In practice, the anatomical region to be examined is asking for more coil elements and receiver channels that are provided as hardware in the MRI apparatus. An MRI

25 apparatus produced and sold by Philips, the Gyroscan NT, which is also used in practice can handle up to six synergy/phased array coils simultaneously by use of six receiver channels, but certain applications could ask for more receiver channels and RF coils. If there are more RF coils than receiver channels it is necessary to select coils for allocation to the available receiver channels. A larger number of receiver channels is possible in principle and would

lead to shorter acquisition times or higher resolutions. But each additional receiver channel increases the costs of an MRI apparatus considerably, and each change in the number of receiver channels necessitates a redesign of the entire system because more bandwidth is required then.

5 It is therefore an object of the present invention to provide an MRI apparatus and an MRI method solving the above-mentioned problems, in particular solving the problem of a limited number of receiver channels and a greater number of RF coils.

This object is achieved by a magnetic resonance imaging apparatus as claimed in claim 1, comprising:

10 an RF coil system for detecting RF signals from a region of interest comprising at least two sets of at least two RF coils,
at least two receiver channels for receiving and processing the detected RF signals, and
a control unit for selecting and/or combining the RF signals of at least two RF
15 coils depending on the imaging parameters and for inputting the selected and/or the combined RF signals into separate receiver channels.

The invention is based on the idea that the user of the MRI apparatus must have the ability to choose which and how many individual smaller RF coils to select and/or
20 combine to effectively encompass and probe the region of interest and to input the RF signals of the selected and/or combined coils into separate receiver channels. Depending on the given examination, in particular the anatomical region to be examined and the given method of examination, the user must have the ability to choose which foldover direction or SENSE
25 reduction direction is best for the given examination. This direction then determines the combination of the smaller coils into larger elements. The direction is known to be manifold in different examinations of the same region. A fixed hardware combination of several small loops as RF coils into one larger loop as RF coil is therefore not desirable. This would require exchanging of coils for different scans within one examination. In particular, in transversal
30 slides left-right-foldover is preferred anatomically in most scans except for Echo Planar Imaging (EPI)-scans where anterior-posterior-foldover is preferred. Generally, Echo Planar Imaging-scans are more sensitive in phase-encoding direction, i.e. the slow-scan-direction, for susceptibility and backfolding artifacts.

In contrast, a variable, preferably software-controlled control unit is provided according to the invention for selecting and/or combining the RF coils, i. e. the phased array/synergy coils, depending on the imaging parameters.

According to the invention a selection and/or combination of RF coils is based
5 on known imaging parameters of the given examination, which imaging parameters can e.g. be the foldover direction or the reduction direction as described in the above-mentioned article. Further, the kind of the given examination and the arrangement and the properties of the RF coils shall be understood as imaging parameters.

Thus it is achieved by the invention that only the most appropriate RF coils or,
10 in the case of a combination, more RF coils than existing receiver channels can be used for detecting RF signals from the region of interest (the region to be examined, e. g. a part of a patient), while maintaining the flexibility to vary the preferential sensitivity direction in xyz-coordinate system for different scans within one examination.

In a preferred embodiment of the invention said control unit is provided for
15 combining the RF signals of several groups of at least two RF coils into a separate receiver channel. In order to enable SENSE in one direction, two or more independent receiver channels (for more than two images) are needed which will be combined into one image using the SENSE algorithm. These two (or more) different receiver channels require two (or more) different sensitivity profiles. Such a sensitivity profile can be obtained from one coil or
20 from two (or more) electrically combined RF coils.

To enhance scan speed or spatial resolution even more the SENSE principle can be used in two directions. This will lead to backfolding in two directions in the individual receiver channels. Consequently, using the SENSE principle in two directions more RF coils or sensitivity profiles are needed. Since these two directions are not (exactly) known
25 beforehand, in each xyz-direction at least two coils or two sensitivity profiles are needed leading to a minimum of eight RF coils in a volumatic position.

In another preferred embodiment said RF coil system comprises two sets of four RF coils. Some anatomical regions such as the head, do ask for a configuration of a set of multiple RF coils arranged around the object, e. g. around the head. Preferably an
30 arrangement of eight coils is used, in particular for examining the head where these coils are preferably arranged in the form of a birdcage head coil arrangement.

In such a head coil arrangement it is further preferred to combine either the RF signals of RF coils arranged on opposite sides of the head or to combine the RF signals of neighbouring RF coils. The selection of which RF signals to combine depends on the details

of the head coil arrangement and on the imaging parameters, e. g. the desired reduction direction.

According to another aspect of the invention said control unit is provided for selecting and/or combining the RF signals of at least two RF coils depending on the phase
5 encoding direction or, according to still another aspect of the invention, depending on the desired SENSE reduction direction.

The object is further achieved by a magnetic resonance imaging method as claimed in claim 9 comprising the steps of:

detecting RF signals from a region of interest using an RF coil system
10 comprising at least two sets of at least two RF coils,
receiving and processing the detected RF signals using at least two receiver channels, and selecting and/or combining the RF signals of at least two RF coils depending on the imaging parameters and inputting the selected and/or the combined RF signals into separate receiver channels. It shall be understood that this method can be developed further
15 and can have further embodiments which are identical or similar to those which have been described with reference to the MRI apparatus as claimed in claim 1.

The invention will now be described in more detail with reference to the following drawings in which

20 Figure 1 shows a diagram explaining certain terms used for explaining the invention,

Figure 2 shows a first embodiment of a head coil arrangement comprising four RF coils,

Figure 3 shows a second embodiment of a head coil arrangement comprising
25 four RF coils,

Figure 4 shows a third embodiment of a head coil arrangement comprising four RF coils,

Figure 5 shows a birdcage head coil arrangement comprising eight RF coils,

Figure 6 shows the birdcage head coil arrangement explaining the combination
30 of RF coils,

Figure 7 shows a first embodiment of a control unit according to the invention, and

Figure 8 shows a second embodiment of a control unit according to the invention.

Figure 1 shows a diagram explaining several terms used for describing the invention. Therein a two-dimensional cartesian grid is shown which grid is arranged in the z-y-direction. The z-direction can be regarded as slice selection direction, and the y-direction can be regarded as phase encoding direction. The known method making use of sensitivity encoding takes advantage of undersampling or reduction of k-space samples and known individual coil sensitivity profiles. The full field of view (FOV) 1 is thus reduced in both dimensions. A pixel 3 in the reduced FOV 2 represents the superposition of pixels forming a cartesian grid. In the example shown in Figure 1 four of these pixels are in the full FOV 1; thus the actual degree of aliasing is four. Aliased pixels are thereby created in the individual coil reconstructed images, which can, however, be unfolded by making use of the different sensitivity profiles of each coil. There are a few constraints on this: reduction of k-space samples, using SENSE, and subsequent effective unfolding of the image, can only be achieved in the direction of multiple receiver coils, i. e. in the reduction direction. The SENSE reconstruction algorithm will unfold the image. Aliasing or foldover artefacts are thus created in the same direction, i. e. in the foldover direction.

Figure 2 shows a first embodiment of an RF coil system according to the invention. Therein two sets of RF coils, each set comprising two RF coils are arranged around the head 4 of a patient which is to be examined. In practice the user wishes to chose the ear to ear direction as the foldover direction for the head, because often the width of the head is smallest in this direction. The user has also reasons for choosing the foldover direction arbitrarily with a view to the signal-to-noise ratio (S/N ratio) and the direction of the desired slice to be imaged. Therefore, use is made of the two sets of coils as shown in Figure 2 comprising one set of LR (=left/right) coils 5, 7 and one set of AP (=anterior/posterior) coils 6, 8. Further, each RF coil 5, 6, 7, 8 is provided with a separate preamplifier 50 each defining a separate receiver channel C1, C2, C3, C4.

If use is made of the known method of sensitivity encoding (SENSE) the direction in which the SENSE reduction axes are situated is known, so that the focus orientation of the coil combination of two from four coils is defined. Using an RF coil system as shown in Figure 2 in one direction SENSE for AP use channels one and four C1, C4 are selected and used separately, i.e. the RF signals thereof are inputted to separate receiver channels, while for LR use channels two and three C2, C3 are selected and used separately according to the invention. In two directions SENSE all four channels are selected and used separately.

Another embodiment of an RF coil system according to the invention is shown in Figure 3 which also comprises four RF coils 9, 10, 11, 12 which are arranged around the head 4 of a patient. Compared to the embodiment shown in Figure 2 the RF coils 9, 10, 11, 12 are angulated by 45° . Again, each RF coil 9, 10, 11, 12 is provided with a separate preamplifier 50 followed each by a phase shifter 51.

For LR SENSE, i.e. if the reduction direction is LR, the output signals of RF coils 9 and 12 are combined into one receiver channel C1 by use of an RF adder/combiner 53, and the output signals of RF coils 10, 11 are combined into a second receiver channel C2 by a second RF adder/combiner 53. For AP SENSE the outputs of RF coils 11, 12 are combined into a first receiver channel and the outputs of RF coils 9, 10 are combined into a second receiver channel, which combinations are not shown in Figure 3.

The described principle can be made software controlled by means of software controlled switches 52 and/or software controlled phase shifters 51 which software controlled switches 52 are shown in the embodiment of Figure 4.

The principle shown in Figure 4 can be extended in z-direction leading to at least eight individual RF coils 21 to 28. In each set of four RF coils 21, 22, 23, 24 and 25, 26, 27, 28 the combinations as shown in Figure 4 can be made.

Some anatomical regions, such as the head, do ask for a configuration of a set of multiple RF coils arranged around the object. An embodiment of such an RF coil system comprising a birdcage head coil arrangement having eight RF coils 21-28 is shown in Figure 5. There is a split in the FH (Feet/Head) direction because this direction will always be used as one of the reduction directions in a 3D MR application using the known sensitivity encoding method. As can be seen in Figure 5 showing two times the configuration of Figure 3 there are two sets of four coils, the first set comprising the coils 21, 22, 23, 24, the second set comprising the coils 25, 26, 27, 28. The individual coils may be bend to achieve a better filling factor. Depending on the MRI examination to be performed the user has to be able to chose on the phase encoding direction whether it is the AP direction or the LR direction.

According to the invention depending on the desired foldover direction some RF coils will be combined into one receiver channel, which combination is controlled preferably by an appropriate software. If the desired reduction direction is the AP direction then four pairs of RF coils are formed, each pair comprising two RF coils, i. e. the RF signals of coils 21 and 24, 22 and 23, 25 and 28, 26 and 27 are combined as can be seen in Figure 6. If, as an alternative, the desired reduction direction is the LR direction the RF signals of coils 21 and 22, 23 and 24, 25 and 26, 27 and 28 are combined according to the invention.

In Figure 10 the arrangement of preamplifiers 50, phase shifters 51, software controlled switches 52 and RF adders/combiners 53 for four receiver channels C1, C2, C3, C4 and eight RF coils 21 to 28 as used in the embodiment of Figure 6 is shown.

It is to be noted that the positions of the phase shifters 51 and the switches 52 can be interchanged. Further, the RF adder/combiner 53 and the phase shifter 52 can be realized by integrated circuits.

The described combinations may require an additional hardware adding the two (or more) RF coil signals with or without some extra phase difference. A control unit in the form of a special software controlled switch box for this function is shown in Figure 8. Therein a control unit 31 is shown having eight inputs for the RF signals of eight RF coils 21 – 28. Further, the control unit 31 has an input for a software controlled bus 32 for control signals and for outputs outputting combined RF signals to four receiver channels 41, 42, 43, 44. These outputs also form the interface 33 between the RF coil system 30 and the processing system 40 of the MRI apparatus.

In case of a head coil arrangement it is advantageous to tilt the head a little for comfort reasons. This will lead to a slightly angulated situation. The preferred SENSE direction will now be angulated. Instead, also the individual RF coils could be tilted to overcome this problem.

It is further possible to place a lot of individual RF coils around an object and only combine a few coils into several independent receiver channels. The channels which are not used will then be inactive. The coils to be used for forming each individual receiver channel (or a sensitivity profile) can be selected by the software controlled bus where use is made from the known SENSE directions (two directions simultaneously and in every possible offset and angulation).

The invention is not limited to the embodiments described above. Several further embodiments are possible. In particular, several variations of the number, the arrangement and the kind of RF coils are possible. Further, the number of receiver channels is not limited to a certain amount.

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CLAIMS:

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1. Magnetic resonance imaging apparatus comprising:
an RF coil system (9, 10, 11, 12) for detecting RF signals from a region of
interest comprising at least two sets of at least two RF coils,
at least two receiver channels (C1, C2) for receiving and processing the
5 detected RF signals, and
a control unit (51, 52, 53; 31) for selecting and/or combining the RF signals of
at least two RF coils depending on the imaging parameters and for inputting the selected
and/or the combined RF signals into separate receiver channels.
- 10 2. Magnetic resonance imaging apparatus as claimed in claim 1,
wherein said control unit (51, 52, 53; 31) is provided for combining the RF signals of several
groups of at least two RF coils into a separate receiver channel.
3. Magnetic resonance imaging apparatus as claimed in claim 1,
15 wherein said RF coil system (9, 10, 11, 12) comprises two sets of four RF coils.
4. Magnetic resonance imaging apparatus as claimed in claim 3,
wherein said RF coil system (9, 10, 11, 12) comprises a birdcage head coil arrangement.
- 20 5. Magnetic resonance imaging apparatus as claimed in claim 4,
wherein said control unit (51, 52, 53; 31) is provided for combining the RF signals of RF
coils arranged on opposite sides of the head.
6. Magnetic resonance imaging apparatus as claimed in claim 4,
25 wherein said control unit (51, 52, 53; 31) is provided for combining the RF signals of
neighboring RF coils.
7. Magnetic resonance imaging apparatus as claimed in claim 1,

wherein said control unit (51, 52, 53; 31) is provided for selecting and/or combining the RF signals of at least two RF coils depending on the phase encoding direction.

8. Magnetic resonance imaging apparatus as claimed in claim 1,

5 wherein said control unit (51, 52, 53; 31) is provided for selecting and/or combining the RF signals of at least two RF coils depending on the desired SENSE reduction direction.

9. Magnetic resonance imaging method, comprising the steps of:

10 detecting RF signals from a region of interest using an RF coil system (9, 10, 11, 12) comprising at least two sets of at least two RF coils,

receiving and processing the detected RF signals using at least two receiver channels (C1, C2), and

15 selecting and/or combining the RF signals of at least two RF coils depending on the imaging parameters and inputting the selected and/or the combined RF signals into separate receiver channels.

The invention relates to a magnetic resonance imaging (MRI) apparatus comprising:

20 an RF coil system for detecting RF signals from a region of interest comprising at least two sets of at least two RF coils,

at least two receiver channels for receiving and processing the detected RF signals, and

25 a control unit for selecting and/or combining the RF signals of at least two RF coils depending on the imaging parameters and for inputting the selected and/or the combined RF signals into separate receiver channels.

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26.01.2001

ABSTRACT:

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The proposed MRI apparatus provides a solution to the problem of a limited number of receiver channels. The main idea is to make use of the imaging parameters when selecting and/or combining the RF signals of at least two RF coils into separate receiver channels which imaging parameter can for example be the phase encoding direction.

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(Figure 4)

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100

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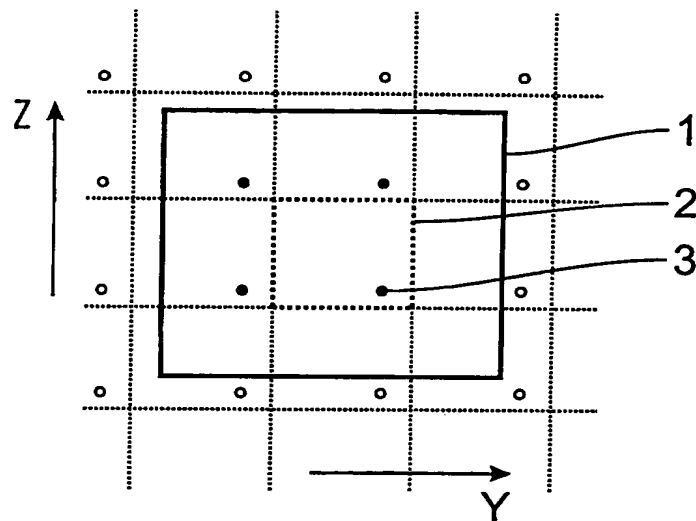


FIG.1

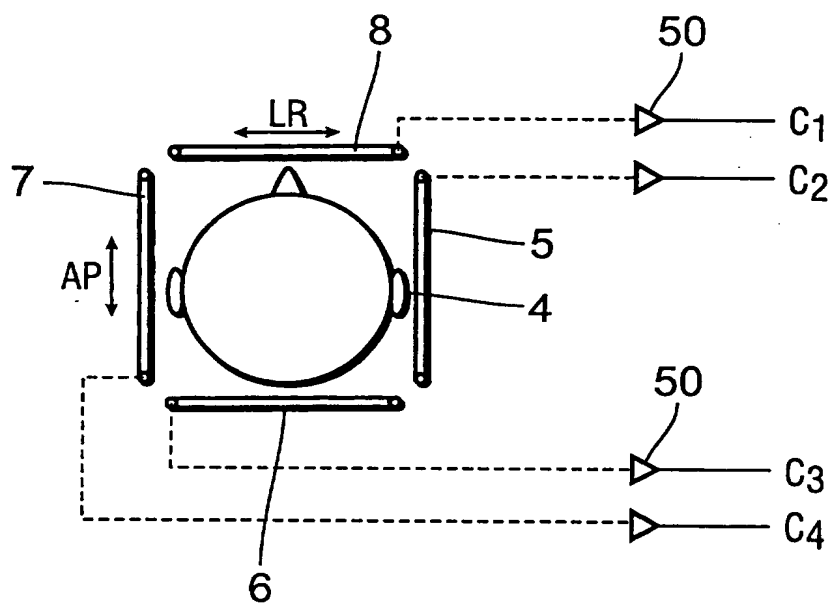


FIG.2

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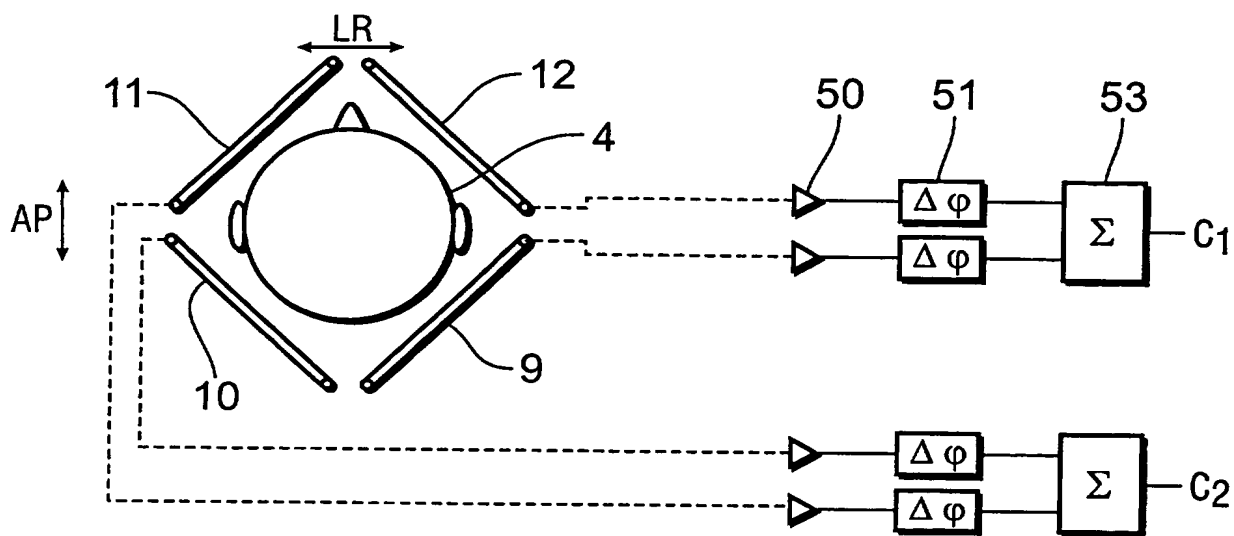


FIG.3

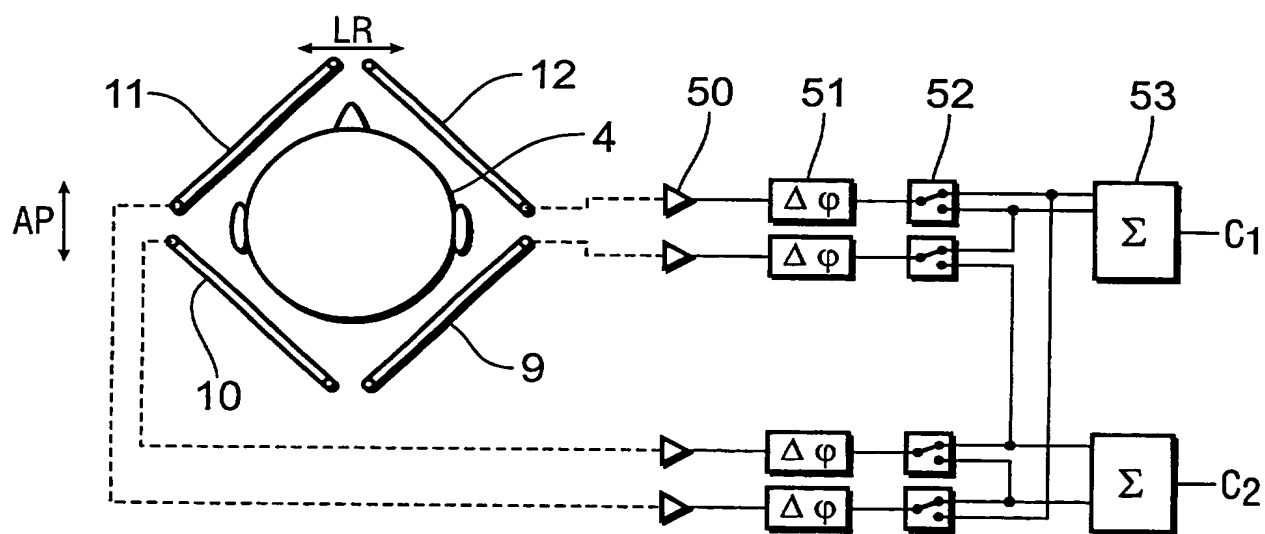


FIG.4

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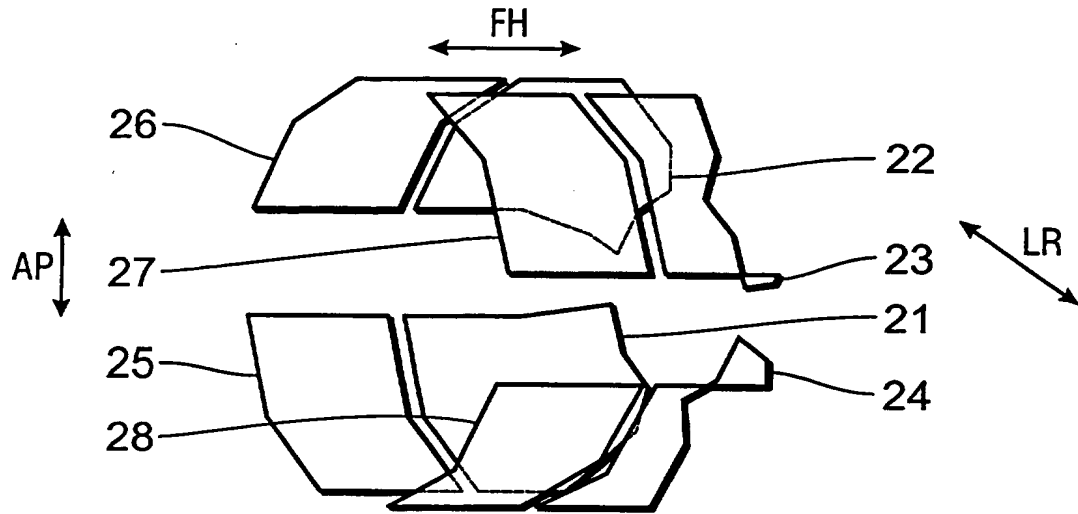


FIG. 5

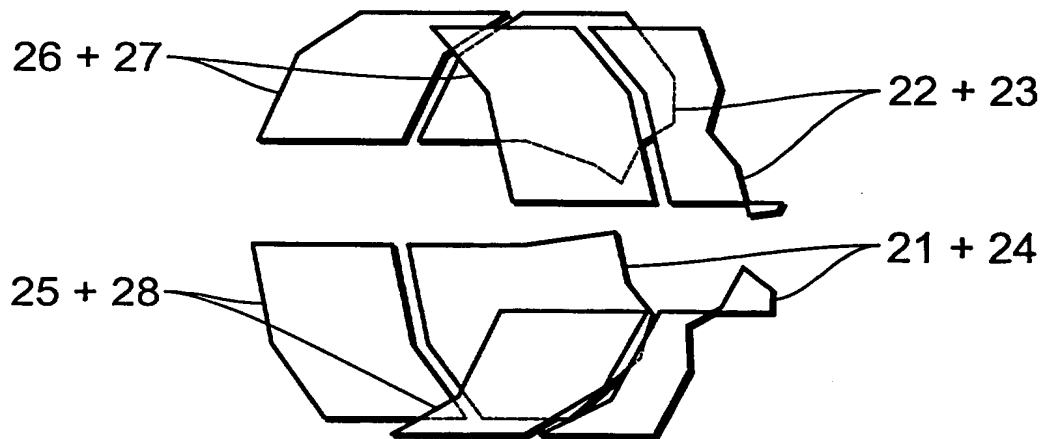


FIG. 6

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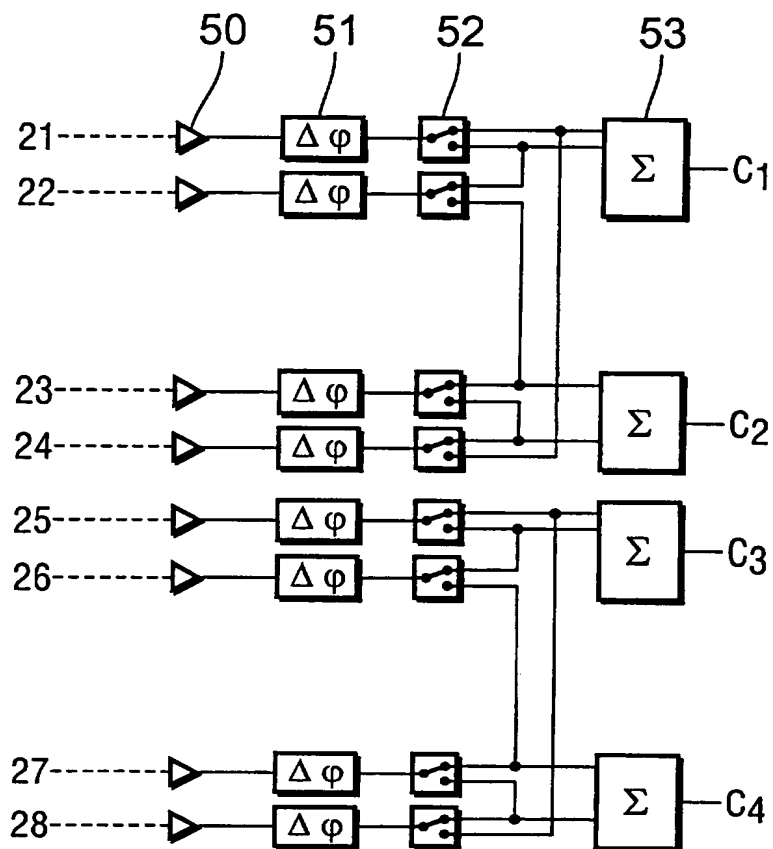


FIG.7

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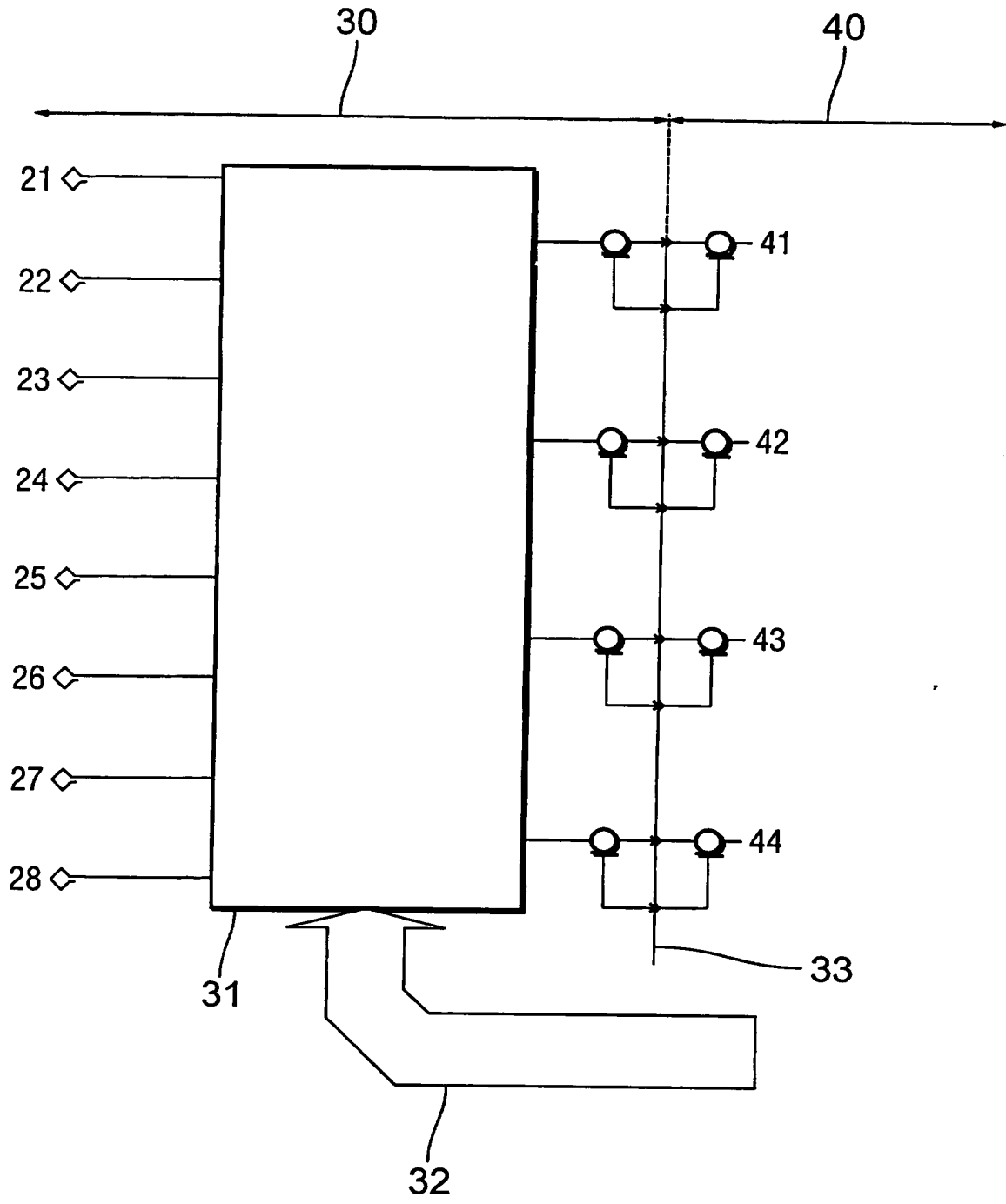


FIG.8

